BRANCH : CIVIL ENGINEERING
NAME OF SUBJECT: FLUID MECHANICS & SUBJECT CODE: 23CIV231T

UNIT I: (9)

Basic concepts and definitions: Distinction between a fluid and a solid; Density, Specific weight, Specific gravity, Kinematic and dynamic viscosity; Variation of viscosity with temperature, Newton law of viscosity; Vapor pressure, Boiling point, Surface tension, Capillarity, Bulk modulus of elasticity, Compressibility

2. SPECIFIC WEIGHT (γ)

STEP 1 : Definition

Specific weight is the weight per unit volume of a fluid.

$$\boxed{\gamma = \frac{W}{V}}$$

Where,

γ = Specific weight (N/m^3)
W = Weight of fluid (N)
V = Volume of fluid (m^3)

STEP 2 : Relation with Specific Gravity

$$\boxed{\gamma = SG \times \gamma_w}$$

Where,

SG = Specific gravity (dimensionless)
γ_w = Specific weight of water = 9.81 kN/m^3

STEP 3 : Example

Find the specific weight of oil having SG = 0.85.

$$\gamma = 0.85 \times 9.81 = 8.3385 \text{ kN/m}^3$$

$$\boxed{\gamma = 8.34 \text{ kN/m}^3}$$

3. SPECIFIC GRAVITY (SG)

STEP 1 : Definition

Specific gravity is the ratio of density (or specific weight) of a fluid to that of water at 4°C.

$$\boxed{SG = \frac{\rho}{\rho_w} = \frac{\gamma}{\gamma_w}}$$

Where,

ρ = Density of fluid (kg/m^3)
ρ_w = Density of water (1000 kg/m^3)
γ = Specific weight of fluid (N/m^3)
γ_w = Specific weight of water (9.81 kN/m^3)

STEP 2 : Example

The density of mercury is 13600 kg/m^3. Find its specific gravity.

$$SG = \frac{13600}{1000} = 13.6$$

$$\boxed{SG = 13.6}$$

STEP 3 : Quick Values (at 4°C)

Water	:	SG = 1.0
Oil	:	SG = 0.8 – 0.95
Mercury	:	SG = 13.6
Seawater	:	SG = 1.025

4. KINEMATIC VISCOSITY (ν)

STEP 1 : Definition

Kinematic viscosity is the ratio of dynamic viscosity to density.

$$\boxed{\nu = \frac{\mu}{\rho}}$$

Where,

ν = Kinematic viscosity (m^2/s)

μ = Dynamic viscosity ($Pa \cdot s$)

ρ = Density of fluid (kg/m^3)

STEP 2 : Units

SI unit : m^2/s

Common unit : Stokes (St)

$1\ St = 10^{-4}\ m^2/s$

STEP 3 : Example

For a fluid,

$\mu = 0.001\ Pa \cdot s$, $\rho = 1000\ kg/m^3$

Find ν.

$$\nu = \frac{0.001}{1000} = 1 \times 10^{-6}\ m^2/s$$

$$\boxed{\nu = 1 \times 10^{-6}\ m^2/s}$$

STEP 4 : Typical Values (at 20°C)

Water : $\nu = 1.0 \times 10^{-6}\ m^2/s$

Air : $\nu = 1.5 \times 10^{-5}\ m^2/s$

Oil : $\nu = 1 \times 10^{-4}$ to $1 \times 10^{-3}\ m^2/s$

5. DYNAMIC VISCOSITY (μ)

STEP 1 : Definition

Dynamic viscosity is the internal resistance of fluid to shear or flow.

$$\boxed{\mu = \frac{\tau}{du/dy}}$$

Where,

τ = Shear stress (Pa)

du/dy = Velocity gradient (1/s)

STEP 2 : Units

SI unit : Pascal-second ($Pa \cdot s$)

Common unit : Poise (P)

$1\ P = 0.1\ Pa \cdot s$

STEP 3 : Example

A fluid develops shear stress of 2 Pa when velocity gradient is $500\ s^{-1}$.

Find μ.

$$\mu = \frac{2}{500} = 0.004\ Pa \cdot s$$

$$\boxed{\mu = 0.004\ Pa \cdot s}$$

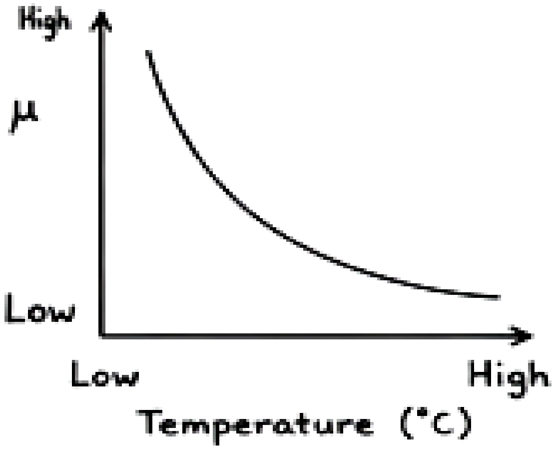
STEP 4 : Typical Values (at 20°C)

Water : $\mu = 0.001\ Pa \cdot s$

Air : $\mu = 1.8 \times 10^{-5}\ Pa \cdot s$

Oil : $\mu = 0.01 - 0.1\ Pa \cdot s$

6. VARIATION OF VISCOSITY WITH TEMPERATURE



- For liquids : Viscosity decreases with increase in temperature.
- For gases : Viscosity increases with increase in temperature.

Example

- Water at 20°C : $\mu = 0.001$ Pa·s
- Water at 60°C : $\mu = 0.00047$ Pa·s

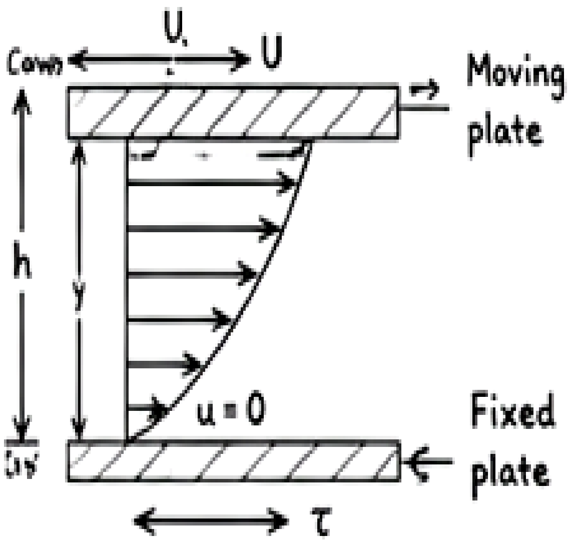
(Viscosity decreases as temperature increases)

7. NEWTON'S LAW OF VISCOSITY

STEP 1 : Statement

The shear stress (τ) is directly proportional to the velocity gradient $\left(\frac{du}{dy}\right)$ for a Newtonian fluid.

$$\boxed{\tau \propto \frac{du}{dy} \quad \Rightarrow \quad \tau = \mu\left(\frac{du}{dy}\right)}$$



Where,

τ = Shear stress (Pa)

μ = Dynamic viscosity (Pa·s)

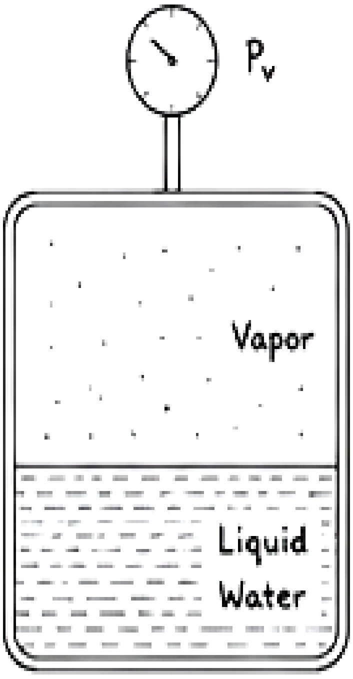
$\frac{du}{dy}$ = Velocity gradient (1/s)

Example

If $\mu = 0.001$ Pa·s and $\frac{du}{dy} = 500\ s^{-1}$,

$$\tau = \mu \frac{du}{dy} = 0.001 \times 500 = 0.5 \text{ Pa}$$

8. VAPOR PRESSURE



STEP 1 : Definition

It is the pressure exerted by the vapor when a liquid is in equilibrium with its vapor at a given temperature in a closed container.

STEP 2 : Key Points

- Vapor pressure increases with increase in temperature.
- At boiling point, vapor pressure = Atmospheric pressure.

STEP 3 : Example

At 100°C, vapor pressure of water = 101.3 kPa
(which is atmospheric pressure, hence water boils at 100°C)

9. BOILING POINT

STEP 1 : Definition

Boiling point is the temperature at which the vapor pressure of a liquid becomes equal to the surrounding pressure.

STEP 2 : Example

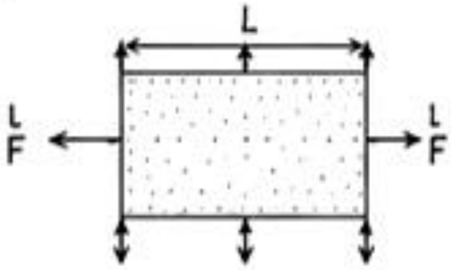
At sea level (P_{atm} = 101.3 kPa), water boils at 100°C.

10. SURFACE TENSION (σ)

STEP 1 : Definition

It is the tangential force per unit length acting at the surface of a liquid.

$$\boxed{\sigma = \frac{F}{L}}$$



Where,
σ = Surface tension (N/m)
F = Force (N)
L = Length (m)

Example

If a force of 0.072 N acts on a 1 m length,

$$\sigma = \frac{0.072}{1} = 0.072 \text{ N/m}$$

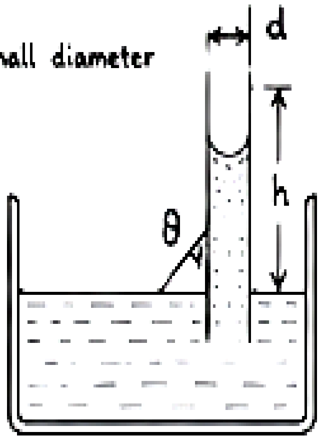
11. CAPILLARITY

STEP 1 : Definition

Capillarity is the rise or fall of a liquid in a small diameter tube due to surface tension.

STEP 2 : Formula

$$h = \frac{4 \sigma \cos \theta}{\rho g d}$$



Where,

- h = Rise (m)
- σ = Surface tension (N/m)
- θ = Contact angle
- ρ = Density of liquid (kg/m³)
- g = Acceleration due to gravity (9.81 m/s²)
- d = Diameter of capillary tube (m)

1. DENSITY (ρ)

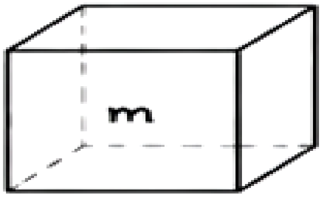
STEP 1 : Definition

Density is the mass per unit volume of a substance.

$$\rho = \frac{m}{V}$$

Where,

- ρ = Density (kg/m³)
- m = Mass (kg)
- V = Volume (m³)



Volume = V

STEP 2 : Units

- SI unit : kg/m³
- Other common units : g/cm³

STEP 3 : Physical Meaning

- Density tells us how much mass is contained in a unit volume.
- Higher density means more mass in the same volume.

STEP 4 : Example

If a block of material has a mass of 7.8 kg and occupies a volume of 0.01 m³, find its density.

Solution :

$$\rho = \frac{m}{V} = \frac{7.8}{0.01} = 780\ kg/m^3$$

$$\boxed{\rho = 780\ kg/m^3}$$

STEP 5 : Typical Values (at 20°C)

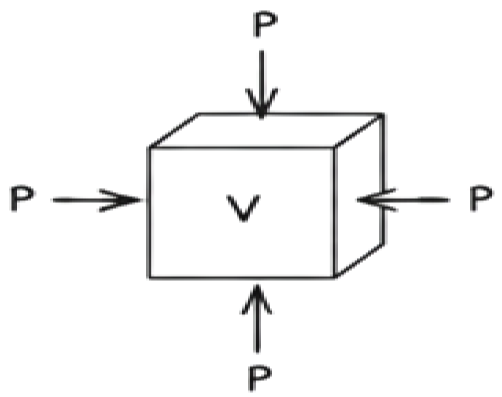
Substance	Density (kg/m^3)
Water	1000
Air	1.2
Aluminium	2700
Steel	7850
Mercury	13600

2. BULK MODULUS OF ELASTICITY (K)

STEP 1 : Definition

Bulk modulus of elasticity is the ratio of intensity of pressure to the fractional change in volume.

$$\boxed{K = -V\frac{dP}{dV}}$$



Where,

K = Bulk modulus (Pa)
P = Pressure (Pa)
V = Volume (m^3)
dP = Change in pressure
dV = Change in volume

STEP 2 : Physical Meaning

- When pressure is applied on a fluid, its volume decreases.
- Bulk modulus measures the resistance of a fluid to uniform compression.

STEP 3 : Units

- SI unit : Pascal (Pa) or N/m^2

STEP 4 : Example

A fluid of volume $2\ m^3$ is subjected to a pressure increase of 1 MPa (1×10^6 Pa) and its volume decreases by $0.002\ m^3$. Find bulk modulus.

Solution :

$$K = -V \frac{dP}{dV} = -(2) \frac{1 \times 10^6}{-0.002}$$

$$\boxed{K = 1 \times 10^9 \text{ Pa}}$$

STEP 5 : Typical Values

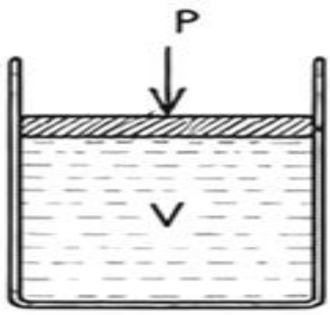
- Water : 2.2×10^9 Pa
- Sea water : 2.4×10^9 Pa
- Oil : $(1.0 - 1.6) \times 10^9$ Pa

3. COMPRESSIBILITY (β)

STEP 1 : Definition

Compressibility is the reciprocal of bulk modulus of elasticity.

$$\boxed{\beta = \frac{1}{K}}$$



Where,

β = Compressibility (Pa^{-1})
K = Bulk modulus (Pa)

STEP 2 : Physical Meaning

- Compressibility indicates how much a fluid will compress for a unit increase in pressure.
- Lower compressibility means the fluid is less compressible (stiffer).

STEP 3 : Units

- SI unit : Pa^{-1}

STEP 4 : Example

The bulk modulus of a fluid is 2.2×10^9 Pa. Find its compressibility.

Solution :

$$\beta = \frac{1}{K} = \frac{1}{2.2 \times 10^9}$$

$$\boxed{\beta = 4.55 \times 10^{-10} \ Pa^{-1}}$$

STEP 5 : Typical Values

- Water : 4.55×10^{-10} Pa^{-1}
- Sea water : 4.17×10^{-10} Pa^{-1}
- Oil : $(6.25 - 10) \times 10^{-10}$ Pa^{-1}

$$\beta = \frac{1}{K} = \frac{1}{2.2 \times 10^9}$$

$$\beta = 4.55 \times 10^{-10}\ Pa^{-1}$$

Step 5 : Typical values

- water :- $4.55 \times 10^{-10} \cdot Pa^{-1}$
- sea water : $4.17 \times 10^{-10}\ Pa^{-1}$
- Oil : $(6.25 - 10) \times 10^{-10}\ Pa^{-1}$

Problems :-

Determine the Specific Gravity of a fluid having the viscosity 0.05 Poise and kinematic viscosity 0.035 sto

Given data ;

viscosity μ = 0.05 poise

= 0.05/10

kinematic viscosity v = 0.035 stokes

0.035 m^2/s

using the relation

$$v = \frac{\mu}{\rho}$$

$$0.035 \times 10^{-4} = \frac{5 \times 10^{-3}}{\rho}$$

$$\rho = 1428.5$$

$$SG = \frac{1428.5}{1000}$$

$SG = 1.4285$

2 Determine the viscosity of liquid having kinematic viscosity is 6 stokes and Specific Gravity is 1.9

Given data

Kinematic ~~vi~~ viscocity $v = 6$ stokes $\Rightarrow 6 \times 10^{-4}$

Specific Gravity $SG = 1.9$

$$SG = \frac{\text{density of liquid } (\mu)}{\text{density of water}}$$

$$1.9 = \frac{\rho}{1000}$$

$$\rho = 1900$$

using the relation

$$v = \frac{\mu}{\rho}$$

$$6 \times 10^{-4} = \frac{\mu}{1900}$$

$$\mu = 1.14 \ N/m^2$$

3 The space between 2 square flate parllel platy is filled with oil each side of plate is 60 cm the thickness of the film is 12.5 mm, the upper plate which moves at 2.5 m/s requires of force is 98.1 N to

to maintain the speed . determine

* The dynamic viscosity of oil in poise

* The kinematic viscosity of oil in stokes if the SG of the oil is 0.95

Given data ;

Each side square plate is = 60 cm = 0.6 m

Area = 0.6 x 0.6

= 0.36 m^2

Thickness of film = 12.5 m

dy = 12.5×10^{-3} m

du = 2.5 m/s

force required upper plate F = 98.1 N

Shear stress $\tau = \frac{\text{force}}{\text{Area}} \Rightarrow \frac{98.1}{0.36}$

$\tau = 272.5$

*

Let

μ = dyamic viscosity of oil

by using the relation

$$\tau = \mu \frac{du}{dy}$$

$$272.5 = \mu \frac{2.5}{12.5 \times 10^{-3}}$$

$$\mu = 1.3625 \ NS/m^2$$

$$\mu = 13.625 \ poise$$

*

kinematic viscosity of oil is 'v'

$$\rho = SG \times 1000$$

$$= 0.95$$

$$\rho = 950 \ kg/m^3$$

using the relation

$$v = \frac{\mu}{\rho}$$

($\because$ poise $= 10^{-3}$

stokes $= 10^{-4}$)

$$v = \frac{1.3625}{950}$$

$$v = 0.0014342 \ m^2/sec$$

$$= 0.0014342 \times 10^{-4} \ cm^2/sec$$

$$v = 14.342 \ stokes$$

4. calculate the specific weight, density, specific gravity of one liter of liquid which weight 7N

given data

1L of volume 'v' = $1/1000 \ m^3$

weight 'w' = 7N

specific weight $= w/v$

$= 7/1/1000 \Rightarrow 7000 \ m^3$

density $= \frac{w}{g}$

$= 7000 / 9.81$

$= 713.55$ kg/m³

Specific Gravity = density of liquid / density of water

$= \frac{713.5}{1000}$

SG = 0.7135 kg/m3

5 Dynamic viscosity of an oil used of lubrication between a shaft and slive is 6 poises, the shaft of diameter 0.4m and rotete at 190 rpm calculate the power last in bearing for a sileve length of 90mm this oil film is 1.5mm

given data

$\mu = 6$ poises $\Rightarrow 6/10$

$= 0.6$ N/m²

diameter of shaft (D) = 0.4m

Area $= \pi \times d \times L$

$= 3.14 \times 90 \times 0.4$

$= 113.04$

speed of shaft (N) = 190 rpm

sileve length = 90 mm

thickness of tensile velocity of shafte

$= \frac{\pi DN}{60}$

$= 3.977$ m/s

using the reqeation

$\tau = \mu \frac{du}{dy}$

du = change of velocity = 3.97

dy = change of distance

$= 1.5 \times 10^{-3}$

$\tau = \mu \cdot \frac{du}{dy}$

$= 0.6 \cdot \frac{3.97}{1.5 \times 10^{-3}}$

$= 1588$ N/m²

shear force on the shaft =

= shear stress x area

$f = 1588 \times 113.04$

$f = 179507.52$

T on the shaft

$$T = \text{force} \times D/2$$

$$= 1179507 \times 0.4/2$$

$$T = 359.6495 \text{ Nm}$$

power lost $= \dfrac{2\pi N T}{60}$

$= 7152.04$ W

Surface Tension :-

6. A surface tension of water in contact ~~angle~~ with air at 20°C is 0.0725 N/m the pressure inside a droplet of water is to be 0.02 N/cm² greter than the out side pressure calculate the diameter of droplet of water

Given data

surface tension denoted by 'σ' is $= 0.0725$ N/m

pressure intensity "p" is $= 0.02$ N/cm²

d = dameter in the droplet

using the relation

$$P = 4 \times \frac{\sigma}{d}$$

$$0.02 = \frac{4 \times 0.0725}{d}$$

$$d = 14.5$$

7 find the surface tension in a soap bubble of 40mm diameter, when the insid pressure is 2.5 N/m² above atomsphere pressure

Given data ,

$d = 40\,mm \Rightarrow 40 \times 10^{-3}$

$P = 2.5$

using the soap bubble equation

$$P = \frac{8\sigma}{d}$$

$$2.5 = \frac{8\sigma}{40 \times 10^{-3}}$$

$$\sigma = 0.0125$$

8 The pressure out side of the droplet of water of diameter 0.04mm is 10.32 N/cm² (atomsphere pressure) calculate the pressure with in the droplet if, surface tension given as 0.0725 N/m of water.

given data

$D = 0.04 \times 10^{-3}\ m$

$P = 10.32 \times 10^{4}\ N/m^2$

$\sigma = 0.0725\ N/m$

$$P = \frac{4\sigma}{d}$$

$$10.32 \times 10^{4} = \frac{4 \times 0.0725}{}$$

$P = 0.725\ N/cm^2$

pressure inside the droplet + pressure ouside of the droplet

$0.725 + 10.32$

$= 11.045\ N/cm^2$

capillarity problems :

Expression for capillarity Rise

$$h = \frac{4\sigma}{\rho g d}$$

Expression for capillarity fall

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

9. calculate capillary rise in a glass tube of 2.5 mm diameter when immersed vertically water & mercury take the surface Tension σ = 0.0725 N/m for water σ = 0.52 N/m for mercury in contact with air the sepicific gravity for mercury is given as 13.6 and angle contact is 130° ?

Given data,

diatmeter of glass tube = 2.5 mm => 2.5×10^{-3} m

Surface Tension for water σ = 0.0725 N/m

Surface Tension for mercury σ = 0.52

SG for mercury = 13.6

Angle contact = 130°

density for mercury (ρ) = 13.6 x1000 kg/m³

- Capitarity raise for water $\theta = 0°$

$$h = \frac{4\sigma}{\rho g d}$$

$$h = \frac{4(0.0725)}{1000 \times 9.81 \times 2.5 \times 10^{-3}}$$

$h = 0.0118\ m$

$h = 1.18\ cm$

• Capillarity for mercury

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

$$= \frac{4(0.52)\cos 130^\circ}{13.6 \times 1000 \times 9.81 \times 2.5 \times 10^{-3}}$$

$h = -0.004 = 0.4\ cm$

∴ The negative sign indicates the capillarity depression

10 calculate the capillarity efforts in mm in a glass tube 4mm diameter when immersed in

• water and mercury the temperature liquid is 20°c a

values surfaces Tension of water & mercury at 20°c in conta

with air 0.073575 N/m and 0.51 N/m the angle of contact

water is 0 and mercury is 130° take density of water at

20°c as equal to 998 kg/m³

Given data ;

$D = 4mm = 4 \times 10^{-3}\ m$

using the capillary raise are despression

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

• capillarity effect for water :-

$\sigma = 0.073575\ N/m$

$\theta = 0°c$

$\rho = 998 \ kg/m^3$ at $20^\circ C$

~~$h = 7.51 \times 10^{-3}$~~

~~$= 7.51 \ mm$~~

$$h = \frac{4(0.073575)\cos 0^\circ}{998 \times 9.81 \times 4 \times 10^{-3}}$$

$h = 7.51 \times 10^{-3}$

$= 751 \ mm$

- capillaryty effect for mercury :-

$\sigma = 0.51 \ N/m$

$\theta = 130^\circ$

$\rho = 13.6 \times 1000$

$$h = \frac{4(0.51)\cos 130^\circ}{13.6 \times 1000 \times 9.81 \times 4 \times 10^{-3}}$$

$h = -2.45 \times 10^{-3}$

$h = 245 \ mm$

~~compressibility (P) problems~~ :-

11. determine the bulk modulus of elasiticity of fluid, If the pressure of the liquid incresead from $70 \ N/cm^2$ to $130 \ N/cm^2$ the volume of the liquid derceses by 0.15 %.

given data;

initial pressure $= 70 \ N/cm^2$

final pressure $= 130 \ N/cm^2$

$dp = 60 \ N/cm^2$

$dV = 0.15 \%$

$$K = -V \frac{dp}{dv}$$

$$= -V \frac{80}{0.15/100}$$

$$= 4 \times 10^4 \ N/cm^2$$

12. what is bulk modulas of elasity of a liquid which is compressed in cylinder from a volume of $0.0125 \ m^3$ at 80 N/cm² pressure to a volume of $0.0124 \ m^3$ at $150 \ N/cm^2$ pressure?

Given data ;

Intial volume $= 0.0125 \ m^3$

final volume $= 0.0124 \ m^3$

decereses in volumn $= 0.0001$

$$-\frac{dv}{V}$$

$$= -\frac{0.0001}{0.0125}$$

Intial pressure $= 80 \ N/cm^2$

final pressure $= 150 \ N/cm^2$

Increase pressure $= 70 \ N/cm^2$

$$k = \frac{dp}{-\frac{dv}{V}} \Rightarrow \frac{70}{-\frac{0.0001}{0.0125}} \Rightarrow -8.75 \times 10^3 \ N/cm^2$$

questions :-

1. Define the following fluid properites

- Density
- Specific Gravity
- Specific weight
- Surface Tension

2. Define the viscosity and types of viscosity

Types of fluids

The fluids may be classifed into 5 types

→ Ideal fluid

→ Real fluid

→ Newtonial fluid

→ un Newtonial fluid

→ Ideal plastic fluid

→ Ideal fluid :-

A fluid which is in compressble and his having no viscosity known as Ideal fluid

Ideal fluid is only imaginer fluid

→ Real fluid :-

It is a fluid with having a viscosity in actuly pratices

Newtonial fuild :-

A real fuild in which shear stress is directly proporational to the rate of shear strain are velocity gradiant is known as Newtoniah fluid

UN Newtonian fluid :-

A real fuild in which shear stress is not proporational to the rate of shear strain or velocity gradiant is known as unnewtonian fluid

Ideal plastic fluid :-

A fluid in which shear stress is more than the yield value and shear stress is proporational to the rate of shear strain are velocity gradiante is known as Ideal plastic fluid